

CCIR Paper on the Radiocommunications Requirements for Systems to Search for Extraterrestrial Life

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Three separate JPL papers and one Japanese paper were originally submitted to Study Group 2 of the International Radio Consultative Committee (CCIR) on the subject of the search for extraterrestrial intelligence. During the Final Meeting of Study Group 2 in Geneva in September – October 1977, a working party headed by Mr. Sam Brunstein of JPL combined these four papers into a single report. This article presents this report in its final CCIR format. The report considers propagation factors, preferred frequency bands, system characteristics and requirements, and interference.

In the three previous issues of the *DSN Progress Report* N. F. de Groot has presented a series of papers on telecommunications for deep space research as adopted by Study Group 2 of the International Radio Consultative Committee (CCIR). The background information contained in the first of those articles (*DSN Progress Report 42-42*) applies equally to this present article.

The Spectrum Engineering Group of the Jet Propulsion Laboratory supports the NASA Ames Research Center in assisting the U.S. Department of State to prepare for the 1979 General World Administrative Radio Conference. This support consists of conducting studies and preparing CCIR documents in connection with the allocation and protection of radio frequency bands to be used in the search for extraterrestrial intelligence (SETI).

Three separate reports on SETI were prepared within the Spectrum Engineering Group and were presented by the United States to the CCIR Study Group 2 Final Meeting held in Geneva during September 1977. A working group, headed by Mr. Sam Brunstein of JPL, was assigned the task of combining the three papers together with a fourth (presented by the Japanese delegation) into a single report. The composite report was recommended to the full international Study Group 2 in Geneva, was approved, and will be presented for adoption by the CCIR Plenary Assembly in mid-1978. Upon approval by that body, the report will be published as part of CCIR Volume 2, *Space Research and Radio Astronomy*.

As with the reports of deep space research telecommunications previously presented in the *Deep Space Network Progress Report*, this SETI paper is also reproduced in its original form to illustrate both the style and format of CCIR documents.

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WORKING GROUP 2-D

DRAFT NEW REPORT

RADIOCOMMUNICATION REQUIREMENTS FOR SYSTEMS
TO SEARCH FOR EXTRATERRESTRIAL LIFE

(Question 17/2)

1. Introduction

Question 17/2 on Radiocommunication Requirements for Systems to Search for Extraterrestrial Life has been adopted by the CCIR. The present Report discusses the general background and technical matters related to this topic.

1.1 Background

Many scientists believe that life is common in our galaxy and that it may develop to a civilization. Civilizations with similar technical achievements to ours could communicate with each other by radio waves up to distances of 100 light years.

Cocconi and Morrison [1959] first pointed out the possibility of communication from an extraterrestrial intelligence (ETI) and proposed to search for a signal. Independently, Drake *et al.* attempted to receive signals from possible civilizations on nearby stars. Similar attempts have been made at other observatories since then, and these works have been reviewed by Sagan and Drake [1975]. The first "aimed" signal was sent to space from the Arecibo Observatory in November 1974 [NAIO, 1975].

Using state-of-the-art technology it is feasible to detect radio signals arriving at the Earth from other civilizations in the galaxy. Such a programme is called SETI (search for extraterrestrial intelligence).

There are presently several SETI programmes in progress [Sagan and Drake, 1975]. These include the following:

- 1) Bridle and Feldman, at Algonquin Radio Observatory in Canada, are searching nearby stars at 22.2 GHz, near the H₂O line.
- 2) Dixon and Cole, at the Ohio State University Radio Observatory, are making an all sky survey near the 1.4 GHz hydrogen line [Dixon, Cole and Kraus, 1977]. This survey has been continuously in progress for three years.
- 3) Drake and Sagan, using the Arecibo Observatory in Puerto Rico, are observing several nearby galaxies at 1 420, 1 653, and 2 380 MHz.
- 4) Kardashev, using the Eurasian Network, in the USSR, is searching for pulsed signals, with hemispherical coverage.
- 5) Troitsky, using the Eurasian Network, is searching for pulsed signals in an all sky survey at 1.9, 1.0 and 0.6 GHz.
- 6) Zuckerman and Palmer, using the NRAO Observatory in Greenbank, are searching nearby F, G, and K type stars near 1 420 MHz.
- 7) The United States National Aeronautics and Space Agency is currently conducting a search near 1.5 GHz.

1.2 Average distance between civilizations

Average distance between the civilizations is inversely proportional to the cube root of the space density of the civilizations, which is proportional to their average life.

For the civilized life within 100 light years to have a high probability, one must assume an average life of at least 10^7 years.

1.3 Other civilizations

Some experimenters may assume that the other civilization is superior to ours, based on the following argument. We have been able to communicate with an equivalent civilization by radio waves only during the last 30 years. Consequently, if they can communicate, but are inferior to us, the state of development of the other civilization must be within the same interval of 30 years. As 30 years is an extremely short time compared with the time scale of evolution of life, the probability that this would occur is very low. Similar arguments show that they are unlikely to be only slightly superior to us. Arguments in the previous section also require an average life of communicating civilizations of the order of 10^7 years. We conclude therefore that the other civilizations are probably superior to ours.

It is also possible that such civilizations have formed a community through radio communications and that they have been continuously sending signals to suggest that we join the community.

1.4 Consequences of success

Interstellar communication is merely hypothetical before the first contact is made. However, as soon as a contact is established, practical implications to us may be significant. The large capacity communication following the first contact may contain information far superior to our knowledge.

1.5 Types of stars to be searched

Stars which are similar to the sun may have planets suitable for life similar to that on the Earth. Such stars have surface temperatures of 4500 to 6500 K and luminosity of 0.3 to 3 of the sun, and are known as main sequence stars with spectral types of F, G and K [Sagan, 1973].

2. Characteristics of the signal

2.1 Transmitted signal

Nothing can be known with certainty about radio signals transmitted by an extraterrestrial, intelligent society (ETI). However, it can at least be assumed that the signals may have any of the characteristics currently known to human science. Thus, the transmitted signals may have any carrier frequency, modulation, e.i.r.p., or polarization. In addition, since the location of the source is unknown, the nature and magnitude of the source Doppler frequency drift is also unknown.

Using practicable terrestrial facilities (100 m diameter antennae, 1 MW transmitter and a 20 K receiver) communication could be maintained at a rate of 10 bps within a distance of 100 light years.

The United States routinely generates an e.i.r.p. of 130 dBW near 2 GHz during planetary radar experiments at Arecibo, Puerto Rico. An e.i.r.p. this high or higher is possible for a signal from an ETI.

Some experts believe that the signal would be from a point source, polarized, variable with time, and have a narrow bandwidth (of the order of 10 Hz). A very simple form of modulation, coding etc., might be used to make processing at this end simple. This assumes that the signal is intended for reception by a civilization other than the one that is transmitting.

In this case, initial contact would be through a beacon signal to establish a large capacity communication. This signal would possibly contain minimum information to let us know their existence, factors related to the communications following, etc. Subjects such as mathematics, geometry, physics etc., might be also contained in order to help us to understand systems of modulation, coding, grammar, etc.

2.2 Propagation considerations

2.2.1 Interstellar medium

The interstellar medium is a magneto-ionic plasma with non-uniform characteristics that vary with time, distance and direction. The medium is inhomogeneous, anisotropic, and dispersive. The result of these properties is a change in the characteristics of the transmitted signal as it passes through the medium.

Changes in the polarization and spectrum of the transmitted signal are especially important.

Faraday rotation

One effect of the medium will be Faraday rotation of the polarization vector. This may be in either direction depending on the characteristics of the path. Rotations as great as 10 radians or more have been observed at a frequency of 1 420 MHz [Whiteoak, 1974].

Since the medium is anisotropic, there may also be some conversion between linear and circular polarization.

Spectral changes

The interstellar medium causes changes in the spectrum of a signal transversing it. If the signal is unmodulated, the medium broadens the signal spectrum; if the signal is modulated, the medium broadens and distorts the modulation spectrum. The effect is to limit both the maximum and minimum bandwidths for observation of a coherent signal.

The best available data concerning limitation of the maximum bandwidth comes from the measurement of pulsars [Lee and Jökipii, 1976]. These measurements indicate that the maximum coherent bandwidth at 1 GHz is approximately 2 000 Hz over a path length of about 10^3 light years. The bandwidth appears to increase with frequency and decrease with distance.

Pulsar observations have also shown the minimum coherent bandwidth to be on the order of 10^{-2} to 10^{-3} Hz.

2.2.2 Atmosphere of the Earth

Attenuation

For clear weather conditions, atmospheric attenuation is a significant factor above about 20 HGz (Report 233-3, Rev. 76, p. 69). When rain is taken into account, attenuation becomes more significant at frequencies greater than 3 GHz. Atmospheric attenuation is shown in Fig. 1, based on data from Report 564 [Geneva, 1974].

Polarization and spectrum

The ionosphere will affect the polarization and spectrum of the signal in transit. The effect is expected to be small compared to the effect of the interstellar medium.

2.3 Arriving signal

2.3.1 Noise

Signals from an ETI will arrive at the Earth mixed with background radiation.

Extraterrestrial

Outside the atmosphere of the Earth, background noise consists primarily of three components. These are: the 2.7 K black body isotropic radiation that fills the universe, galactic noise and quantum noise (caused by fluctuations in the rate of arrival of RF quanta at the receiver) [Oliver, 1973a]. These noise contributors are shown in Fig. 2.

Galactic noise temperature decreases steeply with increasing frequency. It is directional in nature and is maximum at the galactic equator, diminishing rapidly at greater galactic latitudes. At a latitude of $\pm 5^\circ$ it is about twice the amount near the poles.

The black body background noise temperature is constant in the microwave region at frequencies less than about 60 GHz. At higher frequencies it diminishes. This black body background radiation is isotropic.

Quantum noise temperature increases with increasing frequency, but is significantly less than the other contributors below 60 GHz. It is also independent of direction.

The spectra of emissions of molecules and free radicals contained in interstellar space modifies the noise at certain frequencies. Hydrogen, hydroxyl, and formaldehyde are examples.

Near 1 420 MHz the emissions of neutral hydrogen cause the noise to be above the background.

The OH lines, through maser action, are very narrow and are often variable with time [Weaver et al. 1965].

The H_2CO line, through the anti-maser effect, exhibits a negative excitation temperature and, consequently, the background radiation temperature in the direction of dark clouds is below the 3K background temperature. On the basis of current knowledge this is a unique situation [Palmer, et al. 1969].

The resultant total sky noise temperature outside the atmosphere of the Earth is shown in Fig. 3. As can be seen, there is a broad minimum between approximately 1 and 100 GHz, which is called the free-space microwave window.

From the atmosphere of the Earth

The contributions of the atmosphere to sky noise are discussed in detail in Report 234-3 [Geneva, 1974], Vol. V, page 93. The noise contribution of rain is also discussed in Report 564 [Geneva, 1974], Vol. II, page 253. The effect of the atmosphere is to reduce the frequency range of the sky noise temperature minimum.

Total sky noise

When noise effects of the atmosphere are combined with extraterrestrial noise, the frequency of the noise minimum is reduced to the range between 1 and 10 GHz for clear weather, and 1 to 3 GHz for precipitation in rain climate 4 (as an example), considering rainfall rates not exceeded for more than 0.01% for an average year. See Report 234-3. The resultant total sky noise temperature is shown in Fig. 4.

2.3.2 Received flux-density

Signals will have travelled over interstellar distances, and therefore could be at extremely low power flux-density levels upon arrival at the Earth. A graph of power flux-density at the Earth versus e.i.r.p. for sources at various distances is shown in Fig. 5. The distance to the nearest star is about 4 light years, the diameter of the galaxy is about 100 thousand light years, and the distance to nearby galaxies is around 10^7 light years.

2.3.3 Frequency

The frequency and the time rate of change of frequency of the signals arriving at the Earth are unknown.

Frequency drift considerations

If the transmitting source is on a planet of some other star, then relative motion between the source and our search system can occur because of (a) radial velocity of the other star with respect to the sun, (b) orbital velocity of the Earth and of the other planet, and (c) the rotation of the Earth and the other planet.

The first of these leads to a Doppler shift which is for all practical purposes constant over the interval of time of the search.

Planetary orbital motion and rotation produce Doppler frequency shifts that vary nearly sinusoidally with time (Doppler drift).

There could be, for example, four sinusoidal components to the received signal. These are due to the orbital and diurnal motions of the Earth and the transmitter. The magnitude of the Doppler drift is directly proportional to the transmitted frequency.

The effects of Earth motions can be calculated and allowance can be made for its motion.

Frequency drift can also be caused by instabilities in the receiver and in the transmitter.

2.3.4 Modulation

The arriving signal may be unmodulated, or have any of the known modulation types.

If the source modulation bandwidth exceeds the coherent bandwidth of the medium, the modulation will be distorted or destroyed.

Spectral lines in the transmitted signal will arrive with some broadening caused by the propagation medium, but essentially intact.

2.3.5 Polarization

The arriving signal may have any known linear, circular, or elliptical polarization with any orientation.

2.3.6 Direction

Because the source location is unknown, the direction of the arrival is also unknown.

2.3.7 Time of arrival

Signals may be intermittent.

3. Preferred frequency bands

3.1 Receiving sensitivity considerations

Noise

It may be assumed by some experimenters that there is no prior knowledge of the characteristics of the signal sought, or of the signal source distance. This leads to the conclusion that the signal power flux-density from an extraterrestrial source may be very small, and therefore the search must be made in a portion of the electromagnetic spectrum where physical factors allow maximum sensitivity.

Considerations of sensitivity make background radio noise a strong factor in the determination of a preferred frequency band.

Accommodation of the need for maximum available search time means that atmospheric precipitation effects on system sensitivity should also be taken into account for a terrestrial system.

Considering the discussions of §§ 2.2.1 and 2.3.1, the smallest background noise is obtained between 1 and 100 GHz for a spaceborne system. For a terrestrial system, noise is least between 1 and 10 GHz when only clear weather is considered. If rain effects are also taken into account, the noise minimum is reduced to between 1 and 3 GHz.

Frequency drift

Maximum receiver sensitivity is obtained by using very narrowband receiving channels; but, in order for the receiver output to develop fully, the signal must remain in the receiver bandwidth for a time somewhat longer than the reciprocal of the receiver bandwidth. For an arbitrary Doppler frequency drift rate and assuming matched filter detection, it can be shown that [Oliver, 1973b]

$$B = Af_T^{1/2} \quad (1)$$

where

f_T is the transmitted frequency;

B is the minimum channel bandwidth for full response to the drifting signal;

A is a constant of proportionality.

Thus, in order to allow minimum channel bandwidth and the highest sensitivity, it is necessary to confine doppler drift to a single channel during the integration time. For the unknown components this can only be done by receiving at the lowest practical frequency.

Maximum sensitivity

The combined effects of noise and doppler drift on total system sensitivity can be expressed as a figure-of-merit (F_m):

$$F_m = T_S f_S^{1/2} \quad (2)$$

where:

T_S is the total equivalent sky noise temperature;

f_S is the frequency being searched.

The best sensitivity is indicated by the smallest figure-of-merit.

This figure-of-merit is shown in Fig. 6 both with and without the atmospheric noise contribution. The maximum sensitivity is obtained in either case in the 1-3 GHz region. For an earth-based system the maximum sensitivity is near 1.5 GHz.

3.2 Spectral line considerations

Experimenters may also assume that an ETI may place importance on some of the same molecular emission frequencies that are considered important by human science. In this case it may be desirable to search near specific spectral lines.

Cocconi and Morrison [1959] proposed using a frequency of 1 420 MHz (the neutral hydrogen spectral line) which was the only known spectral line at that time. Subsequently, a number of molecular spectral lines have been detected in the microwave and mm wave region, and the selection of the frequency band must be reviewed.

In selecting the line, the following characteristics should be considered:

- (a) The frequency must be known as unique or particular to both parties.
- (b) It must have an intrinsic advantage that is known to both parties.
- (c) There must be a high probability of receiving a signal by chance.

The hydroxyl lines

The lambda-type doubling lines of OH radicals (1 612, 1 665, 1 667 and 1 720 MHz) and K-type doubling line of formaldehyde (H_2CO , 4 830 MHz) have been suggested as being more suitable than the other molecular lines [Morimoto *et al.* 1977].

A frequency 1 666 MHz would be a good choice as it is in the middle of the main components (1 665 and 1 667 MHz), clear from the OH lines, but close enough to be monitored for the lines. Furthermore the lines are regularly monitored with a high frequency resolution in many objects from many observatories, and there is a high possibility that a narrowband artificial signal would be received by chance. This fact must be known to the superior extraterrestrial civilizations.

The formaldehyde line

The formaldehyde molecule at 4 830 MHz exhibits anti-maser action as mentioned in § 2.3.1. A civilization on a star seen by us in front of a formaldehyde cloud could realize this situation and tend to send us signals at this frequency.

The hydrogen line

Observation directly at the hydrogen frequency would suffer from a high background noise. Observations near this line may be profitable.

The "water hole"

The region between the hydrogen line near 1 420 MHz and the set of hydroxyl lines near 1 650 MHz has been called the "water hole." Water based life forms may see this region as significant. These lines of the dissociation products of water are landmarks in that region of the microwave window from 1 to 2 GHz which physical considerations have indicated as most sensitive for the search.

Others

There are, of course, other molecular interstellar lines which might have importance, such as the water line at 22.23 GHz, or the formaldehyde line at 14.5 GHz. However, sky noise and doppler drift considerations make a search near these other molecular transition frequencies less attractive.

3.3 Summary

Considerations of earth-based SETI system sensitivity lead to a preferred frequency near 1.5 GHz. If importance is attached to the hydrogen and hydroxyl lines this frequency region becomes even more attractive.

However, if observers assume that an ETI may attach significance to the noise reducing properties of formaldehyde clouds, then 4 830 MHz is also a preferred frequency.

The bands between the OH lines near 1 650 MHz are considered of secondary preference.

The above considerations are not complete, and a SETI may be carried on at any frequency. Although SETI is a type of space research, it is often performed in the same frequency bands as radio astronomy because of spectral line considerations and the relative lack of radio interference.

4. Search system characteristics and requirements

The factors of §§ 1 and 2 lead to the following requirements on the search system:

- 1) Maximum practicable sensitivity
- 2) Capable of receiving from any direction
- 3) Capable of receiving any polarization
- 4) Capable of searching a large frequency band with very narrowband frequency resolution
- 5) Nearly continuous operation and minimum practical total search time.

4.1 Sensitivity

Under certain conditions the minimum detectable power of a signal is given by [Oliver, 1971]:

$$P = kT \frac{1 + \sqrt{1 + Bt}}{t} \quad (3)$$

where k is the Boltzmann constant, B is the bandwidth of the receiver channel in Hertz, T is the equivalent system noise temperature in Kelvins, and t is the integration time in seconds.

Maximum sensitivity to a coherent signal will be achieved by a combination of low noise temperature, narrowband frequency resolution, long integration times, and antennae with large collecting area.

Because of the unknowns in the possible modulation, best sensitivity and maximum likelihood of detection can be achieved with a system designed to search for and detect single spectral lines (carriers).

4.2 Bandwidth

For matched filter detection, the flux-density detectable by a search system is proportional to the search bandwidth, maximum sensitivity being achieved when the search bandwidth matches the signal bandwidth (which may be as narrow as the interstellar medium permits). At the same time it is necessary to search over a very wide frequency range. Many spectrum analyzers sweep a narrowband receiver across the band of interest. This procedure is not useful for SETI. What is necessary is to simultaneously search many adjacent narrow channels, perhaps as many as 10^9 channels having bandwidths as small as 0.01 Hz. This simultaneous search of many adjacent channels allows the system to reach maximum sensitivity, while at the same time being able to detect a signal which is drifting in frequency due to doppler effect, and also reducing the time necessary to search a very wide frequency band.

4.3 Operation

The SETI search may take decades or longer. The number of directions to be searched is very large; the possibility of intermittent transmissions will require long observation times in each direction; and integration of the receiver output to increase system sensitivity will make each observation relatively lengthy.

Steps must be taken to minimize the total search time, e.g., the system should be automated and designed for nearly continuous all-weather operation.

When a signal is detected, it must be immediately examined to determine if it is an ETI signal. The search system must be sufficiently reliable to do this at any time.

As this work may take a long period without practical results, a special arrangement for continuing the search may be necessary.

4.4 Location

For ground based operations, requirements are similar to those for radio-astronomy services, i.e., a place surrounded by mountains, far from large cities, etc.

In space, the far side of the moon offers freedom from man-made interference and atmospheric emission. The Lagrangian colinear equilibrium point (Fig. 7) in the earth-moon system (60,000 km behind the moon, where the gravitational force is balanced with the centrifugal force so that the observing spacecraft remains eclipsed from the Earth and well removed from the thermal emission from the lunar surface.

4.5 The search programme

SETI programmes to date have examined only a few targets and directions; they have searched over a relatively narrow band, and their sensitivity has been poor compared to the state-of-the-art.

Systems now performing searches are using existing radio telescopes.

Future programmes will have radio antennae dedicated to SETI, will examine many more targets and directions, will search much wider bandwidths, and will be considerably more sensitive than 1977 systems.

To gain increased sensitivity they may: use more sophisticated data analysis techniques; reduce the system noise temperature; reduce the single channel bandwidth; and use larger, more efficient antennae.

Future systems may search the entire sky, or they may look at individual stars. If observers desire to consider the background noise reduction caused by formaldehyde there are numerous stars which can be seen against the background of many dark clouds that cover a substantial fraction of the sky. Table I lists a sample of such stars, which are single stars, brighter than 8th magnitude, of spectral types of F, G, and K and are in front of dark clouds. The column 1 gives names of stars in the catalogue number in the AGK 3 catalogue, column 2, brightness in magnitude, column 3, spectral types, and columns 4 and 5 give equatorial coordinates of the stars.

Optimum search method

The above considerations are based on many debatable assumptions and there are many possible alternative systems; consequently, no single method can be specified as the optimum and it may be best to try several.

4.6 Search system design

Several earth-based SETI systems are currently being planned in the USA with capabilities and system parameters as outlined in Table II.

4.7 Summary

While the exact source direction, frequency, signal polarization, flux-density, modulation and doppler shift are unknown, the considerations discussed in this Report lead to the following conclusions:

- 1) The search system must be very sensitive and have the lowest possible noise temperature;
- 2) the system must be capable of searching large frequency bands continuously with narrowband frequency resolution;
- 3) the system must be capable of looking in any direction;
- 4) the system must sense all possible polarizations.

5. Interference considerations

A system for a search for extraterrestrial intelligence (SETI) will be a receive only system and will not cause interference. The SETI system will be characterized by low system noise temperature, antennae with a large capture area, wide instantaneous bandwidth with narrowband resolution, with signal integration and quasi-matched filter detection techniques. The receivers will have the highest practical sensitivity in order to detect the anticipated low power flux-density signals from an ETI. Hence, a SETI system will be very vulnerable to interference.

The system discussed in this Section is considered to be operating near 1.5 GHz. Other frequencies will also be used, especially ones used by radio astronomy.

5.1 SETI station factors pertinent to sharing

The SETI parameters considered in this Report are taken from Table II. Other values may be examined by using the information from that and this Report.

The minimum detectable signal for this system is -226 dBW in 300 Hz, or -272 dBW/m^2 in 300 Hz using an antenna of 300 metre diameter (such as the radio telescope at Arecibo, Puerto Rico).

5.1.1 Maser saturation

Systems under consideration in the USA envision the use of a maser to achieve the required low noise temperature. Typical masers exhibit nonlinear saturation effects when the total receiver input power in the maser passband exceeds about -120 dBW. Systems used for SETI are considering passbands up to 300 MHz.

5.1.2 Receiver saturation

The signal processor will have a finite linear dynamic range. Thus a sufficiently strong receiver input signal in a single channel will cause saturation. This will in turn cause the generation of spurious signals that will also affect nearby channels.

5.1.3 Minimum detectable signal degradation

A wideband, manmade signal at a level about 10 dB below the minimum detectable signal in each channel will appear to the signal processor as an increase in noise over a number of channels. This will cause a degradation of the receiver performance of about 0.4 dB in those channels.

5.1.4 False signal detection

A manmade coherent signal at or slightly below the minimum detectable level in a channel will be observed and cause a false alarm. This will in turn require observations sufficient to establish the detection as a false alarm. It will also mask a weaker ETI signal that may be present.

5.2 Interference protection

Based on § 5.1, reasonable protection will be afforded if the power in a single channel is about 10 dB below the minimum detectable signal. This requires that the power spectral density of wideband interference or the total power of CW interference in any single band and all sets of bands 1 Hz wide does not exceed -260 dBW/Hz referenced to the input terminals of the receiver.

Because of the possible fleeting nature of ETI signals, interference should not exceed an aggregate of 5 minutes per day. For the reasons discussed in Report 219-2 (New Delhi, 1970) this should be taken as 0.001% of the time for protection from terrestrial transmitters.

Near 1.5 GHz this protection will be afforded for a power spectral flux-density of $-306 \text{ dBW/m}^2 \text{ Hz}$ on the boresight of a 300 meter antenna, or $-235 \text{ dBW/m}^2 \text{ Hz}$ for an isotropic receiving antenna.

5.3 Sharing considerations

5.3.1 Line-of-sight paths

Consider the conservative case of a transmitting station with 1 dBW of power, a 0 dBi antenna, and the modulation uniformly spread over 1 MHz. The station would exceed the interfering power spectral flux-density given in § 5.2 for an isotropic receiving antenna at a range of approximately 160,000 km.

This leads to the conclusion that sharing with spaceborne stations is not practicable. Sharing with airborne stations above the horizon of a SETI station is also not practicable.

5.3.2 Over the horizon paths

Sharing with most ground-based transmitters appears feasible if an appropriate coordination procedure is adopted.

Sharing with high powered earth-based systems such as troposcatter and radiolocation may be difficult.

This sharing case requires further study.

5.3.3 Reflection from spaceborne objects

The reflection of terrestrial signals from spaceborne objects near earth may also cause a problem. This case needs further study.

5.4 Summary

Frequency sharing between a receiving SETI system and spaceborne or line-of-sight airborne transmitting systems is not feasible.

Frequency sharing between a receiving SETI system and earth-based transmitting systems is probably feasible in most cases with appropriate coordination.

6. Other cases

Although the above considerations are based on a number of reasonable assumptions, there are also several reasonable objections. Three important ones are outlined.

(a) There is an argument that transmitting a radio signal may be more efficient than just searching for signal. It was also pointed out that the first artificial radio signal occurred 60 years ago and this signal has already travelled 60 light years, and may be detected by a civilization within this distance. However, such unaimed signal at a distance of 60 light years is very weak and would be difficult to detect by other civilizations.

If the communicating civilization is regarded as far superior to ours, transmission of an aimed signal must not be attempted without due consideration of unexpected problems.

(b) Bracewell [1960] considered the possibility of a first contact through a space probe from the other civilization. Generally a space probe could be considered as uneconomical and therefore unlikely. However, several variations are possible and a more careful study is warranted.

(c) Morimoto [1967] has suggested a gaseous creature, which causes a population inversion in certain molecules in its body and sends and receives radio signals through maser action.

These possibilities are ignored in the present Report.

7. Conclusions

7.1 Preferred frequency bands

If experimenters assume that there is no a priori knowledge of the ETI signal, then considerations of maximum sensitivity and maximum search bandwidth lead to the conclusion that the region near 1.5 GHz having a bandwidth of several hundred MHz is a preferred region for SETI examination. Because of the possible significance that other water based life may attach to the spectral lines of hydrogen and hydroxyl radical, it is desirable that the band include these spectral lines. It should be defined so as to allow a reasonable search bandwidth on either side of these lines.

Consideration of these factors establishes a preferred frequency band several hundred MHz wide, near 1.5 GHz.

However, if observers assume that the ETI has knowledge of the location characteristics of formaldehyde clouds, and is considering their shielding in transmitting to the Earth, then a narrowband of frequencies centered at the 4 830 MHz formaldehyde line would be a preferred frequency.

Other frequencies will also be used, especially those currently used by radio astronomy. As the determination of optimum frequencies continues, other preferred bands will emerge.

7.2 Interference considerations

Some currently planned SETI systems will need protection at the receiving level of -235 dBW/m²Hz near 1.5 GHz, if the antenna is assumed to have isotropic gain away from the main beam.

Some other SETI systems will use frequencies also used by radio astronomy. The protection currently considered appropriate in Report 224 will be adequate for their protection.

As the SETI systems and frequencies become better defined, additional protection criteria will emerge.

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Key words:

Extraterrestrial intelligence

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Galactic civilizations

Interstellar communication

*Available for consultation in the CCIR Secretariat.

TABLE I.

A partial list of candidate stars for search at 4 830 MHz

AGK 3	No.	Magnitude	Type	Right Ascension	Declination (1950)
+58 ^o	161	2.8	F5	0 ^h 6 ^m .5	+58 ^o 52'
54	395	6.7	F5	4 5.4	54 42
38	491	6.2	F5	4 38.4	38 11
22	518	6.1	K0	5 16.3	22 3
+ 1	618	7.0	G5	5 44.0	+ 1 9
- 1	639	8.3	K2	5 46.2	- 1 48
+ 2	647	6.9	G0	5 47.9	+ 2 1
1	630	6.3	K0	5 49.8	1 51
6	643	7.7	G5	5 49.8	6 12
6	646	7.9	G0	5 50.8	6 15
3	717	7.9	K0	5 51.6	3 13
0	594	7.6	K0	5 52.5	0 58
2	684	7.3	K0	6 7.2	2 53
15	1946	7.9	G0	18 53.8	15 18
12	2040	8.4	G0	18 59.0	12 33
18	1834	8.0	K5	19 13.3	18 26
9	2447	6.7	F8	19 20.4	9 49
21	1990	8.6	G5	19 26.5	21 53
22	1969	8.7	K2	19 27.7	22 36
21	2002	7.6	G5	19 31.3	21 44
8	2614	7.6	K0	19 42.9	8 36
33	1851	7.9	K0	19 52.3	33 39
34	1945	8.0	K0	19 53.1	34 46
34	1947	5.0	K0	19 54.4	34 57
45	1663	8.1	K2	20 15.0	45 11
44	1848	7.8	G5	20 52.1	44 12
43	1905	7.9	K5	20 53.6	43 11
42	1952	7.5	K0	20 54.5	42 35
43	1910	7.9	K0	20 54.6	43 42
42	1956	8.4	K0	20 55.6	42 15
43	1923F	5.1	K5	21 3.1	43 44
57	1436	7.3	F8	21 23.6	57 52
54	1439	7.1	K0	21 39.1	54 39
49	1851	7.1	K0	21 40.8	49 22
60	1419	8.3	K0	21 50.9	60 6
56	1555	7.0	K2	22 14.6	56 58
59	1619	8.3	K0	23 25.9	59 47
58	1565	7.6	K0	23 28.9	58 53
59	1625	8.5	K5	23 29.4	59 11
58	1567	8.2	K2	23 29.4	58 49
60	1574	7.9	K0	23 31.0	60 8
60	1575	8.2	K0	23 31.3	60 12
+61	1471	7.6	K2	23 40.1	+61 24

TABLE II.

Earth-based SETI system characteristics

System noise temperature	10 K
Frequency resolution bandwidth	0.01 to 300 Hz
Integration time	10 to 10^5 sec
Number of adjacent frequency channels searched simultaneously	10^6 to 10^9
Bandwidth searched simultaneously	1 to 300 MHz
Tuneable frequency band capability	1 to 25 GHz
Polarizations received simultaneously	2 to 6
Minimum detectable signal power*	-226 dBW
Minimum detectable signal flux-density for a 300 m diameter antenna (e.g., Arecibo, Puerto Rico).*	-272 dBW/m ²
<p>*These values are based on a 300 Hz resolution bandwidth, 10^4 second integration time, and 60% antenna aperture efficiency. Values for other system parameters may be calculated using equation (3) and the antenna capture area.</p>	

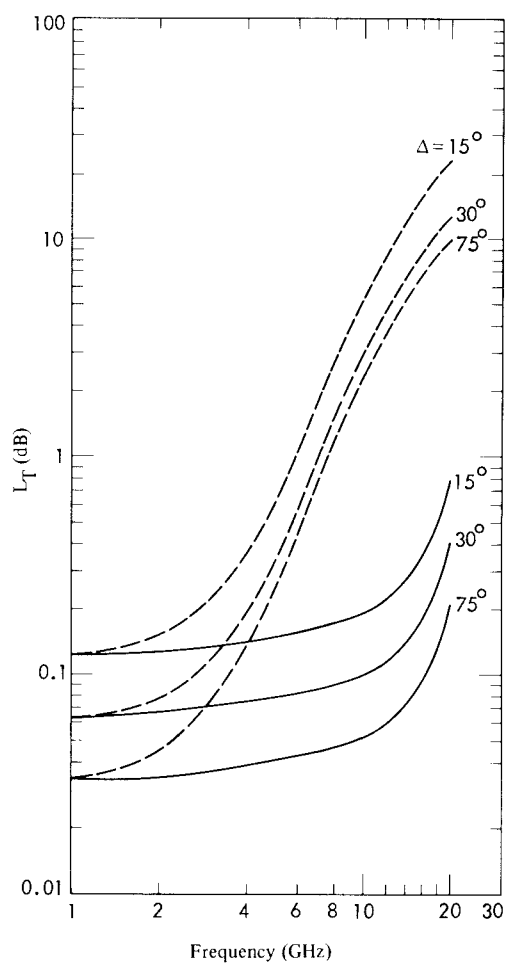


FIGURE 1
Space-to-earth attenuation (L_T)

--- rain and atmosphere
 — clear weather, atmosphere only
 Δ : elevation of earth station antenna

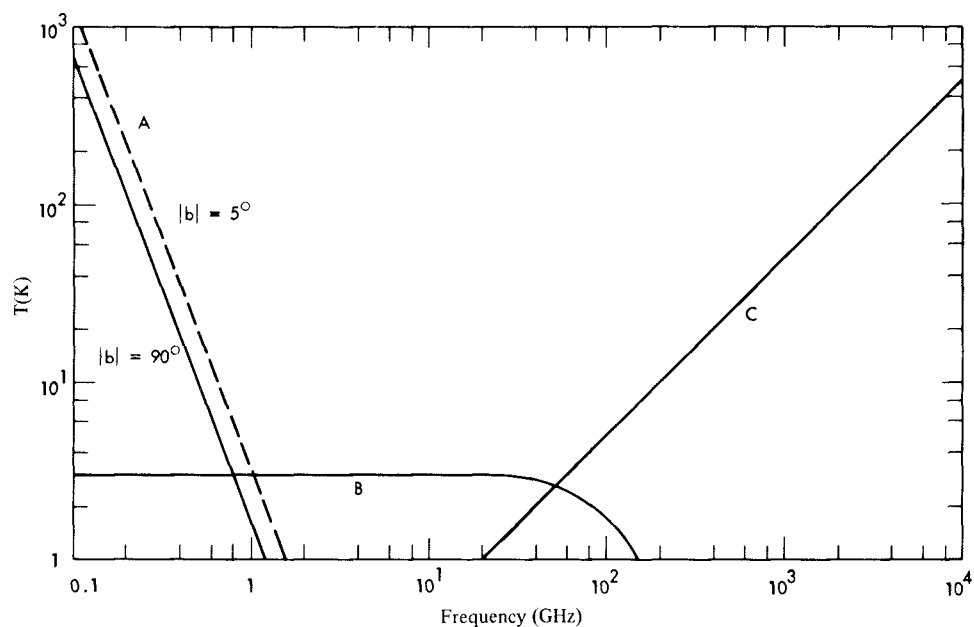


FIGURE 2

Background noise temperature (T) contributors outside the atmosphere of the earth

- A: Galactic
- B: Black body
- C: Quantum effect
- $|b|$: Absolute value of galactic latitude

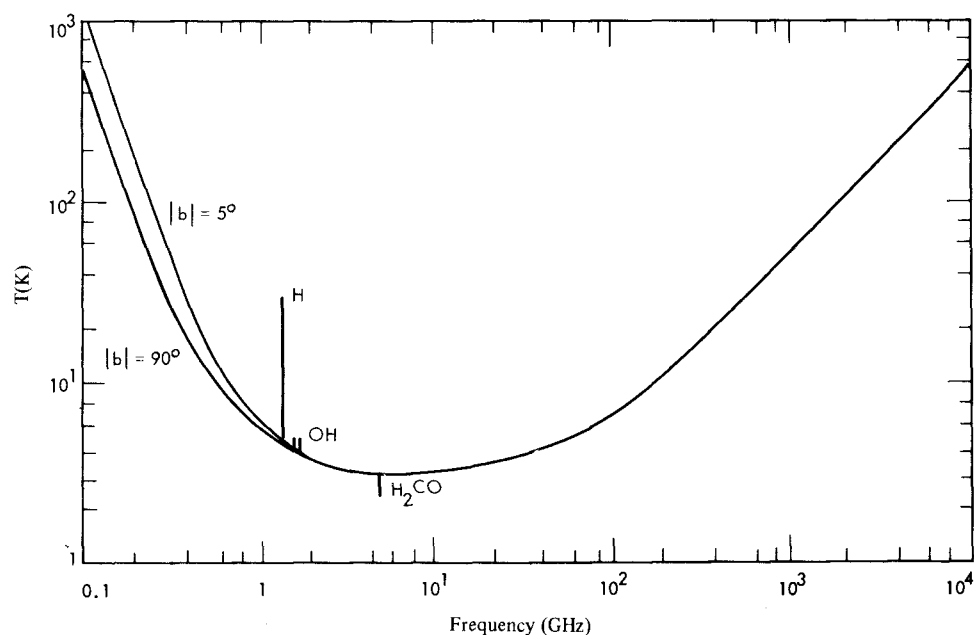


FIGURE 3

Total sky noise temperature (T) outside the atmosphere of the earth

$|b|$: the absolute value of the galactic latitude

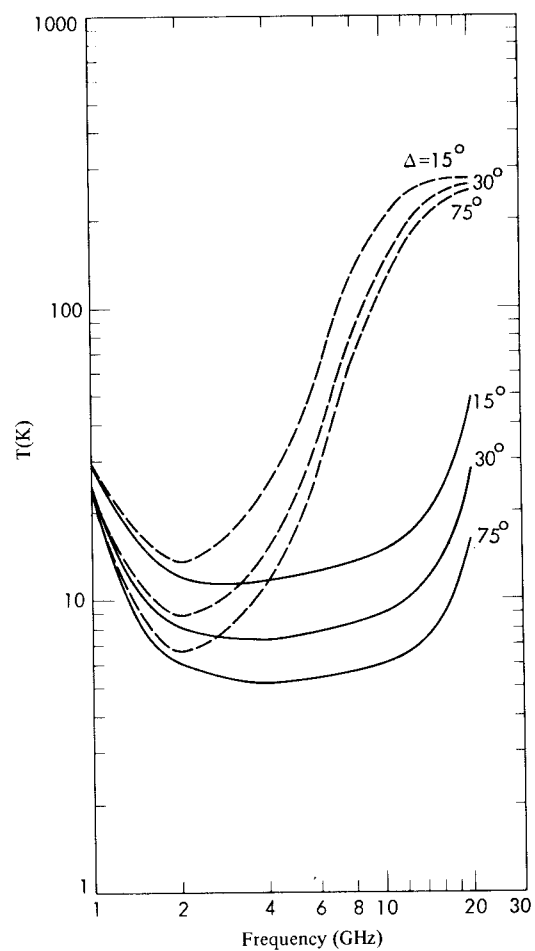


FIGURE 4

Total sky noise temperature (T) seen from the surface of the earth

- rain and atmosphere
- clear weather, atmosphere only
- Δ : elevation of earth station antenna

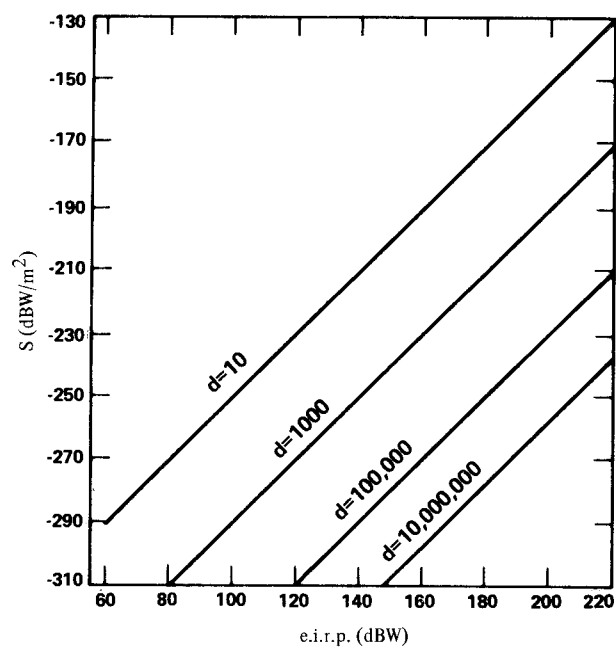


FIGURE 5

Received flux density vs. effective isotropically radiated power for unattenuated sources at various distances

d is distance in light years

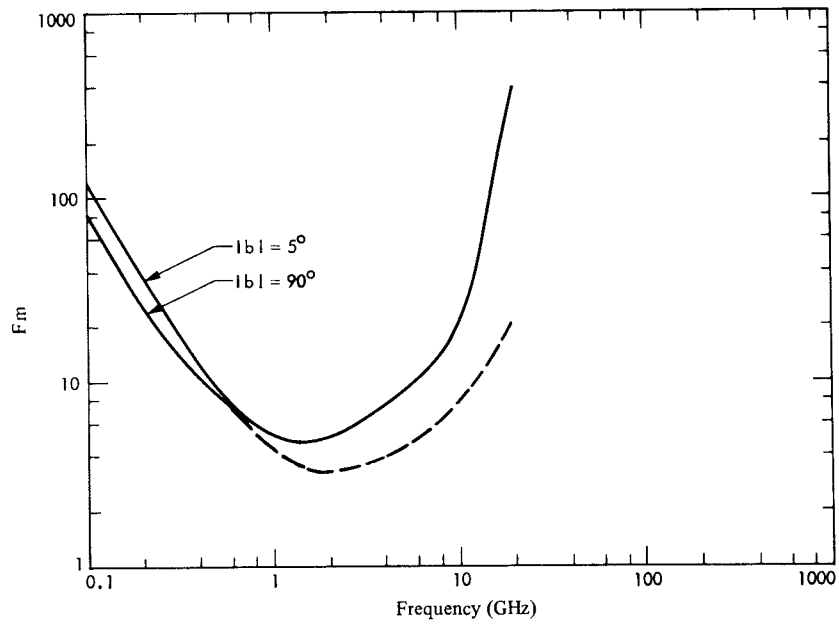


FIGURE 6

Combined noise and doppler drift system sensitivity figure of merit (F_m)

$|b|$: The absolute value of the galactic latitude

- Including zenith atmosphere noise
- - Extraterrestrial noise only

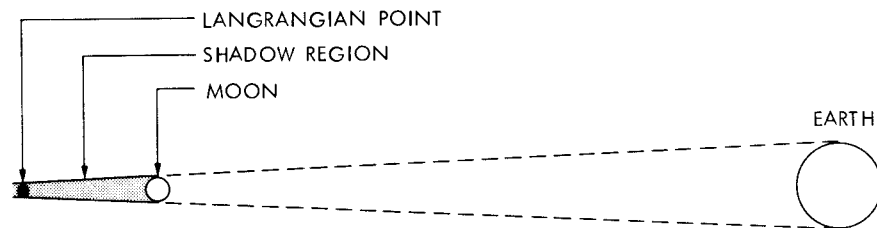


FIGURE 7

Lagrangian collinear equilibrium point